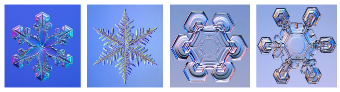

Written exam, 27.01.2023, 09:15 – 11:15, CM 1 4, (120min); total: 60 Points

Instructions / Information: (same as on Moodle, posted and announced on 04.01.2023).

Open book exam - permitted resources and tools: course slides, personal notes, exercises and solutions, pocket calculator. Personal laptop **exclusively** for browsing the slides. The use of smartphones is not authorized (please bring a **pocket calculator**). Any type of communication and exchange (e.g., phone, SMS, chat, email, etc.) is NOT allowed and considered as cheating. Any suspicion requires further investigation (see "Internal directive concerning examinations at EPFL" LEX 2.6.1, Article 6).

Each question has its point value (in red, **"XP"**) and indicative time for answering (in blue, **"Xmin"**). The small red circles ° in the questions indicate the distribution of points. Please use a black or blue ball-pen for writing. Always give the correct/appropriate units of your results. Document intermediate steps leading to your final answer. In case of questions, give a sign; supervisors will assist. Please write your name on all sheets you return. - **Good luck !**

Hendrik, Johan, Michi, Sonja, Adrien, Yael, Tatjana, Minyang

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Values of variables or constants:

- Density of water at 0°C: 1000 kg m^{-3}
- Specific heat capacity of water at 0°C 4220 J kg^{-1} K^{-1}
- Specific heat capacity of ice at 0°C 2110 J kg^{-1} K^{-1}
- Latent heat of fusion of water 3.34e5 J kg^{-1}

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1. Energy balance, radiation (3P – 5min)

During a dust storm the albedo of a snowpack decreases from 0.85 to 0.55. Compute the relative change in net shortwave radiation (in %). ° What does that mean for the snow pack in terms of temperature and potential melt? °°

2. Snow properties and microstructure (9P – 15min)

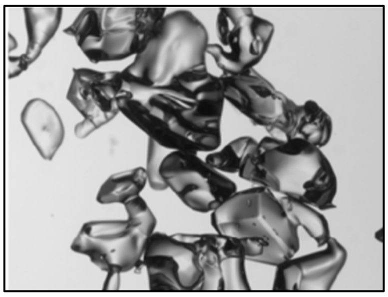
Examine the snow microstructure shown on the pictures below. Photo width corresponds to 6 mm.

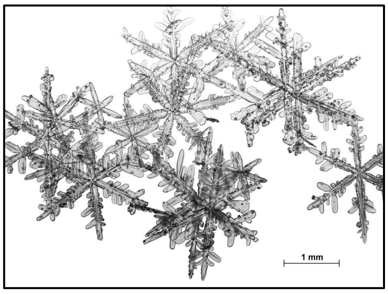
(a) Attribute the correct grain type (see list below) to the ice particles shown in the pictures: °°°
(A) new snow, (B) small rounded grains, (C) large rounded grains, (D) facetted grains, (E) cup crystals, (F) melting grains

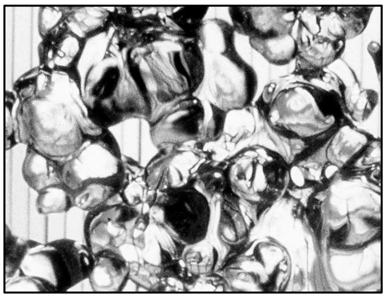
(b) Attribute a corresponding metamorphism process acting just before the picture was taken. °°°

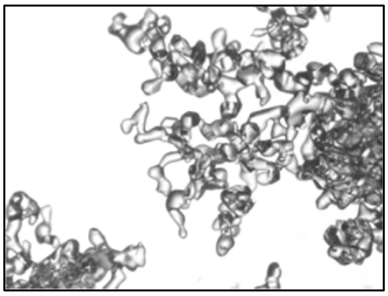
(c) Mention whether the metamorphism in (b) leads to mechanical strengthening or weakening of the snow pack structure. °°°

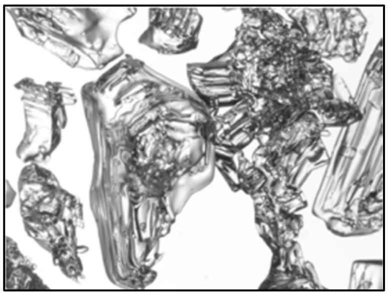
Suggestion: a table may be a convenient way to answer Question 2, (a) – (c).

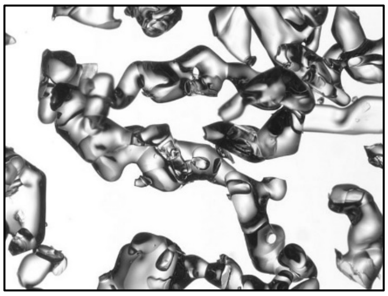
(1) 

(2) 

(3) 

(4) 

(5) 

(6) 

3. Energy balance, rain on snow (16P – 35min)

A 50cm snowpack of uniform density (360 kg m^{-3}) has an isothermal temperature profile of -2°C. A rain event adds 2mm of 3°C warm water on the snow. Assume that the water percolates uniformly into the snow with a horizontal front descending everywhere at the same speed.

(a) Explain qualitatively what happens to the water and the snowpack once they are in contact. °°°°
(b) Will the rain event in this scenario trigger liquid water output at the base of the snowpack? °°°°
(c) How deep into the snowpack would the water percolate in this case? °°
(d) Why is this scenario only theoretical and which process/es would you expect in reality? °°°
(e) With climate change, we will see more rain-on-snow (ROS) events. Explain briefly what a ROS event means for snow melt dynamics, especially when the snow temperature is very close to the melting point. °°°

4. Renewable Energy and Snow (15P – 30min)

Consider a vertically installed bi-facial (active on front- and backside) photovoltaic (PV) panel on a flat infinitely extending surface located at 47°N, e.g., in Davos (Switzerland). The panel surfaces are facing South and North, respectively.
On the 21st of December at local noon (highest sun elevation), the sky is clear (no clouds). At this moment, the sun elevation is about 20° and the global solar radiation measured by a horizontally leveled pyranometer equals 350 W m^{-2} (see Figure 1). 30% of the measured irradiation is due to diffuse light. (Diffuse light is typically uniform in all directions everywhere in the atmosphere under clear sky conditions.) The rest is direct (beam) irradiation.

(a) Assuming no reflection at the Earth's surface (albedo = 0), calculate the global (total) solar irradiation to the surfaces of the panel (both sides). °°°°°
(b) Assuming the ground is covered in snow (high albedo) and that snow forward scattering reflects 30% of the incident beam directly to the solar panel's surface (i.e., the surface acts like a mirror for the fraction of forward scattered radiation), calculate the portion of irradiation exclusively due to the presence of snow on ground. °°°

(c) Taking the irradiation on the south face of the panel in situation (a) as 100%, express the relative total irradiance both on the south and north face of the panel for situation (b). °°°

(d) Finally, for each situation, give reasons why the assumption made may under- or overestimate the irradiation on the solar panel. °°°°

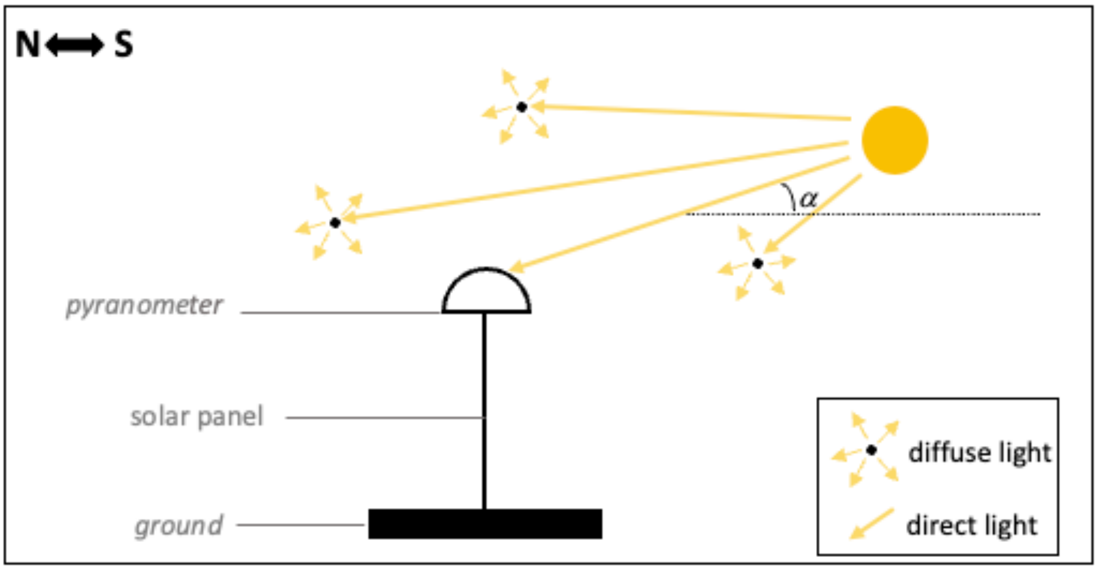


Figure 1: *Scheme of radiation measurement with the pyranometer. α is the sun elevation angle. NB: For direct beam radiation, the pyranometer measures the component normal to the sensor plane (cosine law).*

5. SNOWPACK, Erosion and Slopes (17P – 35min)

A SNOWPACK simulation (with snow transport from windward to lee slopes as presented in the lecture) for the high-alpine station "Gessi" close to the town of Livigno (IT) of the current 2022/23 winter season gives the results shown in Figure 2. Slope inclination and orientation are indicated on the Figure. Note the different scale of snow depth on the y-axis in both panels.

(a) Which are the two dominant processes explaining the differences between the north-facing and south-facing slope? ° Indicate the time periods during which these drivers were dominating the snow cover development. °° In particular, explain differences in snow depth and the disappearance of snow in October.° Describe at least two additional prominent events/processes or features of the snow pack. °°

(b) Based on the simulations shown in Figure 2, can you tell the direction of strong winds present in October and early November, and then later in early December? °°

(c) Which slope would you pick to ski on? Give a justification for your choice. °°

(d) For the north-facing slope, consider the weak layer identified by SNOWPACK based on the SK38.

(i) Is this weak layer persistent or non-persistent? °°

For this weak layer, the associated slab has a thickness of H=54 cm and a mean density of ρ=200 kg m^{-3}.

(ii) Use the SK38 value calculated by SNOWPACK to back-calculate the shear strength of the weak layer and comment on its value (take a skier line load R=500 N m^{-1}, and $\alpha_{max} = 54.34°$). °°°

(iii) Use the strength–density relationship provided by Jamieson and Johnston (2001) to give the density of the weak layer. °°

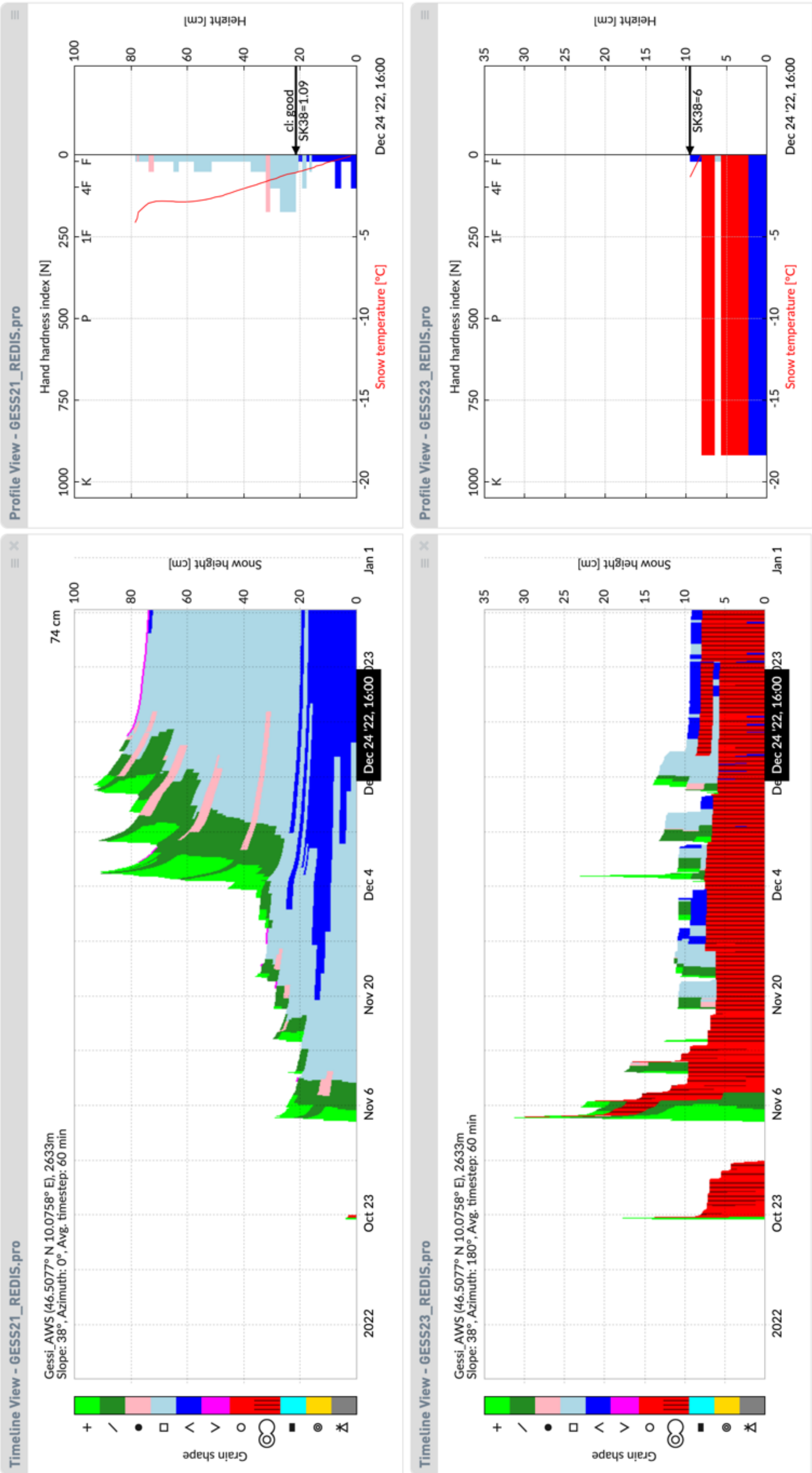


Figure 2: *SNOWPACK simulation result for a virtual North (upper panel) and South (lower panel) slope driven my meteorological measurements close to the town of Livigno (IT).*